

Can Flat Spectrum Radio Quasars make most of the overall γ -ray background ?

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Abstract. The contribution of discrete sources to the γ -ray background is modeled. Flat spectrum radio quasars are known to make a substantial contribution to the hard ($E > 100$ MeV) background. The so called “MeV bump”, however, cannot be accounted for in terms of known classes of sources even taking into account the newly discovered class of objects with a broad band spectrum sharply peaked in the MeV range (“MeV blazars”). Even in the most optimistic case the predicted intensity falls short of at least a factor three.

Key words: galaxies:evolution – galaxies:nuclei – quasars:general – cosmology:diffuse radiation – gamma rays: observations

1. Introduction

The most important discovery of the CGRO EGRET in the field of the extragalactic astronomy is the detection of high energy γ -rays ($E > 100$ MeV) from active galaxies. At present (Thompson et al. 1995) some 50 sources have been identified. All these objects appear to emit most of their bolometric luminosity in γ -rays and are strong, core-dominated, flat spectrum ($\alpha \leq 0.5$ at a few GHz; $F_\nu \propto \nu^{-\alpha}$) extragalactic radio sources. The majority have been identified with quasars while about ten are classified as BL Lac objects.

Even if the precise value of the isotropic γ -ray background (GRB) above a few tens of MeV is still uncertain because of the need to subtract the galactic contribution, there is now strong evidence that the flat spectrum radio quasars (FSRQ) can supply most of the extragalactic background radiation above 30 MeV, with

smaller fractional contributions from BL Lacs and normal and starburst galaxies (Setti & Woltjer 1994; Erlykin & Wolfendale 1995).

The origin of the “MeV bump” remains a major puzzle. Contrary to earlier suggestions the recent results on Seyfert spectra (Johnson et al. 1994) indicate that they cannot provide any major contribution to the MeV band. On the other hand it is very difficult to conceive a physical mechanism taking place at cosmological distances which can account for the large amount of energy involved in the “MeV bump” and, at the same time, being consistent with the very sharp drop of the background spectrum from several MeV down to 30 MeV.

Therefore, we have investigated the possibility that the “MeV bump” could be accounted for in terms of the summed contribution from FSRQ, or a fraction thereof, which are known to possess hard X-ray spectra. While a straight extrapolation of the X-ray spectra ($\alpha > \simeq 0.5$) to higher energies cannot provide any major contribution to the “MeV bump”, the recent discovery by COMPTEL of several FSRQ (usually referred to as “MeV blazars”) with enhanced emission in the MeV band, well above the extrapolation of their X-ray spectra, may provide some hope that a subclass of FSRQ could account for the “MeV bump” (Bloemen et al. 1995).

The purpose of this work is to estimate the contribution from FSRQ to the GRB using the available γ -ray properties recently discovered by CGRO COMPTEL and EGRET observations coupled with the available informations at radio and X-ray wavelengths. Throughout this paper the values $H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and $q_0 = 0$ have been used.

2. The model

Our model for the synthesis of the overall GRB is anchored to the X-ray emission properties of FSRQ at 1 keV. The parameters for the broad band X- and γ -ray

spectrum and cosmological evolution of FSRQ have been chosen in order to obtain a good fit to the overall set of observational constraints. All the assumed parameters are consistent, within the errors, with those suggested by the present available observations.

The local emissivity at 1 keV of $9.7 \times 10^{19} \text{ W Hz}^{-1} \text{ Gpc}^{-3}$ can be derived from the emissivity at 5 GHz of $5.6 \times 10^{26} \text{ W Hz}^{-1} \text{ Gpc}^{-3}$, which is consistent within 1σ with that obtained from FSRQ luminosity function by Maraschi & Rovetti (1994), by applying an average broad band spectral index $\langle \alpha_{rx} \rangle = 0.88$. The adopted value of α_{rx} has been derived from the 1 keV fluxes of a large sample of FSRQ observed with the *Einstein* IPC (Wilkes et al. 1994) and in the ROSAT All Sky Survey (Brinkmann et al. 1994, 1995), and with the 5 GHz fluxes reported by Stickel et al. (1994). [Here and in the following the broad band spectral indices α_{12} are defined as $-\log(L_2/L_1)/\log(\nu_2/\nu_1)$ where L_1 and L_2 are the rest-frame luminosities observed at the frequencies ν_1 and ν_2].

For a typical FSRQ a broken power law spectrum with $\alpha_x = 0.5$ and $\alpha_\gamma = 1.2$ has been assumed. The adopted α_x is an extrapolation from the mean α_x value of the FSRQ detected by the *Einstein* IPC (Wilkes et al. 1994, Wilkes & Elvis 1987) and at higher energies by EXOSAT (Comastri et al. 1992), while α_γ is the mean value in the EGRET band (Thompson et al. 1995). The break energy is defined by the requirement that the local emissivity at 100 MeV is such that, with the cosmological evolution parameters described below, one can account for a fixed fraction of the high energy GRB.

For the FSRQ pertaining to the “MeV blazars” type we have adopted a broken power law spectrum with $\alpha_x = 0$, $\alpha_\gamma = 2$ and a break energy at 2.5 MeV. These spectral parameters are in good agreement with the recent COMPTEL observations of a few of these peculiar objects (Williams et al. 1995, Bloemen et al. 1995).

The evolution is parameterised as a power law such that the luminosity $L(z) = L(0) \times (1+z)^\beta$. The determination of evolutionary properties of the γ -ray sources is made difficult by their small number and variability. Chiang et al. (1995) have found, using the V/V_{max} test, a best fit evolutionary parameter $\beta = 3.0^{+0.5}_{-0.7}$ assuming $q_0=0.1$. This value is consistent with those found for FSRQ in other regions of the electromagnetic spectrum: $\beta \simeq 3$ in the radio band (Dunlop & Peacock 1990) and $\beta \simeq 2.5 - 3$ in the X-ray band (Della Ceca et al. 1994). We have therefore adopted $\beta = 3$. Following the results of Dunlop & Peacock (1990), Boyle et al. (1993) and Warren et al. (1994) the evolution is cut-off at a redshift $z_{cut} = 2.5$, then the emissivity is assumed to be constant up to $z_{max} = 5$, and zero for larger redshifts.

The predicted background intensity in the energy range 1 keV – 1 GeV has been computed assuming that 95% of the local emissivity at 1 keV is due to the FSRQ and the remaining 5% to the “MeV blazars”. This ratio reflects the fact that only a few “MeV blazars” have been

discovered from COMPTEL compared with the roughly 40 FSRQ in the EGRET band.

In Figure 1 we have reproduced a selection of data on the X- and γ -ray backgrounds. For the high energy GRB we have plotted the results from the SAS-2 data analysis of Thompson & Fichtel (1982) and those obtained by Osborne et al. (1994) on the basis of the EGRET Phase 1 data from the CGRO archives. A more recent analysis of the EGRET data has been presented by Kniffen et al. (1995). The derived slope of the GRB spectrum above 30 MeV ($\Gamma \simeq 2.1$) is consistent with that reported by Osborne et al. (1994), while the normalization at 100 MeV is about a factor 1.3 higher. The solid line is the sum of three distinct contributions (dashed lines): the fit to the X-ray background (XRB) obtained with the AGN model of Comastri et al. (1995) and the FSRQ contributions to the GRB derived in the present model. It should be immediately noted that the fraction of FSRQ with an MeV excess cannot account for more than about 10–20% of the “MeV bump” intensity, unless their number is largely underestimated and/or their evolution properties are different. *It should be remarked, however, that the new results presented by the COMPTEL collaboration at the conference in which this work has been submitted appear to convincingly disprove the existence of the “MeV bump”. In Fig.1 we have plotted the COMPTEL results from the paper of Kappadath et al. (1995). It is seen that they are in very good agreement with the intensity derived in our model.*

The contribution of FSRQ to the GRB is of the order of 70–80 % that derived from the EGRET data at 100 MeV. With the model’s parameters it corresponds to a local emissivity at 100 MeV of $3.8 \times 10^{16} \text{ W Hz}^{-1} \text{ Gpc}^{-3}$, that is to the assumption of an average broad spectral index $\langle \alpha_{x\gamma} \rangle = 0.66$ which is a reasonable compromise between the observed mean value of EGRET identified FSRQ, $\langle \alpha_{x\gamma} \rangle \simeq 0.57$, and the observational bias towards finding objects with flatter $\alpha_{x\gamma}$.

It should be noted that the contribution of FSRQ to the XRB becomes appreciable only above a few hundred keV and, therefore, it does not affect the XRB fit obtained with the AGN model of Comastri et al. (1995).

The FSRQ intensity resulting at 1 keV with our model is consistent with the extrapolation, at the same energy, of the total flux due to the flat spectrum radio sources at 5 GHz (i.e. 360 Jy sr^{-1}) calculated by Setti & Woltjer (1994). This extrapolation has been made with a computed $\langle \alpha_{rx} \rangle = 0.91$ and considering that the BL Lac contribution to the total flux is no more than 5%, as can be calculated using the radio fluxes at 5 GHz given by Dondi & Ghisellini (1995) and remembering that BL Lacs do not show any evidence of cosmological evolution. Another 10% contribution is likely to be due to different type of sources.

In order to make full use of the available data we have made an attempt to predict a Log N–Log S relationship and a redshift distribution and compare them with those

Fig. 1. The predicted X- and γ -ray backgrounds (solid line) with the three distinct contributions (dashed lines) of FSRQ, “MeV blazars” and of the AGN model of Comastri et al. (1995; labeled as “XRB fit”). The thick error bars in the MeV region represents the recent results obtained by COMPTEL (see Kappadath et al. this conference). The high energy GRB points above 30 MeV are from Osborne et al. (1994).

obtained with EGRET. For this purpose we actually need a γ -ray luminosity function. Since the published information does not allow us to compute it on the basis of γ -ray data only, we have followed the approach of Padovani et al. (1993) based on the existence of a strict correlation between the radio and γ -ray luminosities of blazars. First we have investigated the correlation between the radio and the γ -ray luminosities (K-corrected) of EGRET FSRQ finding a best fit relation $L_\gamma \propto L_R^{1.36 \pm 0.33}$. Then we have considered the FSRQ luminosity function given by Maraschi & Rovetti (1994) as: $dN/dL_r \propto L_R^{-\gamma}$, with $\gamma \simeq 2.4$. It follows that the derived γ -ray luminosity function is a power law with a flatter slope $\gamma \simeq 2.0$. However the predicted redshift distribution is not fully consistent with the observed one.

A better approximation to the observed redshift distribution (Figure 2) has been obtained with a slightly different luminosity function: a broken power law with a slope of 1.5 above a minimum luminosity of 5×10^{45} ergs s $^{-1}$ and before a break luminosity of 3×10^{47} ergs s $^{-1}$ and a slope 2.4 up to a maximum luminosity of 10^{49} ergs s $^{-1}$, while the normalization is obtained by the consistency with the local emissivity at 100 MeV as given above. We note that some indication of a flattening towards low luminosities is also present in the Maraschi & Rovetti (1994) radio luminosity function. The expected source counts are presented in Figure 3, together with the observational data where we have taken the maximum observed fluxes as reported in Thompson et al (1995). All quoted values concern 10.4 sr outside the galactic plane ($b > \pm 10^\circ$) as in Chiang et

al. (1995). A straightforward comparison of the predicted counts with the observed ones is obviously difficult given the source time variability.

We note that if the observed point at the brightest end of the Log N – Log S (13 objects all together) would be moved to a lower flux limit by an average factor of two, to somehow correct for the time variability of the sources, it would still be consistent within 1σ with our predicted source counts. On the other hand it is clear that the sky-coverage at fainter fluxes must be progressively much lower, as suggested by the flattening of the observed counts. In fact a V/V_{max} test assuming an homogeneous sky-coverage at the faintest detected flux provide a mean value of $\simeq 0.33$, suggesting either a negative evolution (which can be excluded on the basis of radio and X-ray evolutionary properties) or a loss of sources at faint EGRET fluxes. This is also consistent with the redshift distribution (Figure 2) where it is seen that the observed number of objects in the first redshift bin is much lower than the predicted one: low luminosity fainter objects are mostly contributing to this redshift bin.

3. Conclusions

The γ -ray properties of FSRQ are such that they can account for most of the GRB above 30 MeV but not for the “MeV bump”. To this end one would require a large fraction of the FSRQ to be “MeV blazars” which is contrary to the findings obtained by the combined COMPTEL and EGRET observations. The predicted MeV background in-



Fig. 2. The observed redshift distribution (solid line) of the so far identified EGRET FSRQ (Thompson et al. 1995) compared with the predicted distribution (dashed line).



Fig. 3. The predicted Log N – Log S distribution for FSRQ compared with EGRET observations, adopting the maximum fluxes reported by Thompson et al. 1995.

tensity is a factor from 5 to 10 below the fit of the “MeV bump” given by Gruber (1992) and it may very well account for the much lower background intensity presented by the COMPTEL collaboration.

From the radio luminosity function of the FSRQ and its time evolution we have derived a γ -ray luminosity function at 100 MeV which is consistent with present constraints on the total number of FSRQ and their redshift distribution obtained with the EGRET survey of the γ -ray sky. However we note that the unknown EGRET survey sky-coverage prevents us from a detailed comparison between the observational data and model predictions.

As a general conclusion it appears that various classes of AGN are able to account for most of the extragalactic background radiations observed over the very wide energy interval from about 1 keV to tens of GeV.

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